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(54) NON-DESTRUCTIVE METHOD OF GRADING WOOD MATERIALS

(71) We, WASHINGTON STATE UNIVERSITY RESEARCH FOUNDATION, a non-profit agency of the State of Washington, United States of America, of Room 436, French Administration Building, Washington State University, Pullman, Washing 99163, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The invention set out herein relates to non-destructive testing of wood for the purpose of developing information useful in selecting or allocating lumber and other wood materials to their best purposes. The term "non-destructive-testing" is of relatively recent origin in the wood industry, although non-destructive testing techniques have been used in other industries for various purposes. The specific field of application herein relates to non-destructive testing of wood to arrive at numerical values for mechanical properties of a particular specimen. Such properties have previously been available only through destructive tests which of necessity rendered the tested specimen useless. By use of the invention set out herein, an actual specimen can be tested and evaluated prior to use of the specimen for structural or other purposes, thus ensuring efficient use of materials. Further, such testing can also be utilized in providing an evaluation of a specimen in order to guide the user in making the most advantageous application of the actual mechanical properties of an individual specimen. Such individual evalation of specimens is particularly desirable in the case of wood members, because of the inherent variability of wood as a material.

The basic purpose of evaluation of individual wood specimens is to place these pieces in commercial grade categories. These grade categories permit marketing of discreet product groups (grades) based on the physical and mechanical properties of the pieces falling in the groups. The mechanical properties associated with a grade are often values close to the minimum demonstrated by any piece in the grade; thus, to obtain the optimum efficiency in the grade the mechanical properties of individual pieces must be accurately assessed to reduce variability within the grade to a minimum. The inherent accuracy of the invention herein described makes possible improved grading efficiency in several important specific areas of the forest products industry.

The non-destructive testing of wood involves a number of different testing methods which fall into two general divisions: (1) Those which detect anomalies in the wood structure of a specimen, and (2) those which correlate non-destructively measurable quantities with mechanical properties that would otherwise require some permanent damage or change for direct measurement and quantitative evaluation of mechanical properties. Such measurements can be accomplished by the present method along a selected length of a specimen which might be only a fraction of the total specimen or might be along the full length thereof.

To summarize the prior art, grading of wood materials is generally accomplished today by visual inspection, the reliability of such grading being influenced by the skill and experience of the individual inspector. The few production mechanical grading devices in use today are inherently limited in application to specific materials (such as lumber) having definite physical requirements (such as constant cross section). Such devices cannot detect small local areas of low strength with accuracy. They cannot therefore produce highest efficiency in product utilization where grading systems specify allowable design values for properties, such as modulus of rupture in tension, which are significantly influenced by such local discontinuities.

The need for greater accuracy in grading of lumber is reflected by the recent lowering of allowable design values for modulus of rupture in tension for lumber. Visual grading techniques have been found to be incapable of the accuracy required by previously accepted values.

Additionally, present non-destructive production testing devices are limited in application to products that can be bent or mechanic-

ally vibrated. Flexibility and constant rectangular dimensions are necessary. Grading of logs, poles and other irregular large products is limited to visual inspection and measurement. No effective non-destructive grading process is available to directly relate log quality to wood utilization and resulting lumber quality.

The present invention seeks to provide a relatively simple method of arriving at numerical values for mechanical properties of solid wood specimens regardless of continuity of the cross sectional areas of the specimens. It is therefore applicable to the grading of beams and natural wood members such as logs or posts, which vary in dimension. It does not require elaborate or precise supports. It requires no physical contact with the specimen except for the imparting of a singular momentary impact force. It permits the recording of mechanical properties in a fraction of a second. It permits localized measurements of modulus of elasticity leading directly to accurate grading for modulus of rupture in tension.

According to one aspect of the invention there is provided a non-destructive method of grading wood materials wherein mechanical properties of a wood specimen such as lumber, a log, a pole, a beam or a veneer are determined along a selected length of the specimen by means of a longitudinal energy wave propagation through the selected length comprising placing a sensor at each of the two ends of the selected length, each sensor being of a type capable of detecting the passage of an energy wave along the specimen, physically impacting the specimen to set up an energy wave within the specimen traveling in a longitudinal direction along the selected length of the specimen between the sensors, measuring the time of passage of the energy wave between the sensors, and grading each specimen according to a predetermined relationship for its species between the mechanical properties of the specimen and the measured time of passage of the energy wave through the selected length.

According to another aspect of the invention there is provided a non-destructive method of grading wood materials, such as lumber, logs, poles, beams, or veneers according to mechanical properties of wood specimens wherein said properties are determined along a selected lenegth of a specimen by means of longitudinal energy wave propagation through the selected length thereof, comprising locating a first sensor in proximity to a surface of the specimen at one end of the selected length thereof, the sensor being of a non-contacting type responsive to the piezo-electric effect in wood, locating a second sensor proximity to a surface of the specimen at the remaining end of the selected length thereof, impacting one end of the specimen to set up an energy wave within the specimen traveling in a longitudinal direction along the selected length of the specimen between the sensors, activating a timer responsive to signals from the first and second sensors and measuring the time of passage of the energy wave between the sensors, and determining mechanical properties of the specimen as related to the measured time of passage of the energy wave through the selected length thereof.

According to a further aspect of the invention there is provided a non-destructive method of grading wood materials wherein mechanical properties of a wood specimen such as lumber, a log, a pole, a beam or a veneer are determined along selected lengths of the specimen by means of energy wave propagation through the selected lengths thereof comprising placing a sensor along the specimen at individual positions located at each of the two opposite ends of each of the selected lengths thereof, each sensor being of a type capable of detecting the passage of an energy wave along the specimen, physically impacting one longitudinal end of the specimen to set up an energy wave within the specimen traveling in a longitudinal direction along the selected lengths of the specimen between the sensors, measuring the time of passage of the longitudinal energy wave between the sensors located at the ends of each selected length of the specimen, and grading the specimen according to its dynamic modulus of elasticity as derived for each selected length thereof from the formula: $E=C^2\rho$ where E is the dynamic modulus of elasticity, C is the velocity of wave propagation (length of the selected length divided by the time of passage of wave) and ρ is the specimen density, and further grading according to a predetermined relationship for its species between ultimate strength and said modulus of elasticity.

The preselected length may be the entire specimen or any section thereof.

Specific embodiments of the invention will now be described by way of example with reference to the accompanying drawings, in which:

Figure 1 is a block diagram illustrative of the apparatus used according to the method of this disclosure;

Fig. 2 is a somewhat diagrammatic side elvation of an illustrative apparatus used according to the invention;

Fig. 3 is a plan view of the apparatus in Fig. 2; and

Fig. 4 is a diagrammatic plan view of a portion of a wooden specimen having a specific natural defect, illustrating the manner in which the present method can be applied to measure the mechanical properties of this portion of the specimen.

The method described herein is concerned with a "non-destructive" method of determining mechanical properties. By "non-destructive" is meant that the testing procedure does not modify or change the configuration or

basic properties of the specimen being tested. The method can be applied to specimens of wood material having any cross sectional shape or length. It is applicable to specimens varying in cross sectional dimension. The wood material might be in the form of a natural log, a pole, boards or structural timber of various widths, thickness or length. It also is applicable to relatively thin members such as strips of veneer.

The method can be used to determine the average mechanical properties along the entire specimen or can be used for testing preselected portions of a specimen to reveal mechanical properties along such portions which might depart significantly from the average of the entire specimen. It provides a positive basis for accurate mechanical grading of lumber.

The method basically comprises the placing of sensors (2 or more) along the solid specimen at opposite ends of the portion being tested. The specimen is then impacted to set up an energy wave traveling between the sensors. The time of passage of the energy wave between the sensors (Δt) is measured. This time is used to arrive at the velocity of the wave between the sensors, the velocity and density of the material being usable in deriving the dynamic modulus of elasticity (E_d) for the specimen. The measured time of passage of the energy wave and resulting determination of dynamic modulus of elasticity lead to determination of other mechanical properties. Comparison of the numerical results of this method and conventional laboratory testing of the specimens have demonstrated a very high correlation between the results obtained by the present method and the results proven by laboratory techniques.

Fig. 1 shows schematically the general arrangement for carrying out the present method. The solid wood specimen is freely supported by a support 10 that leaves one end e of the specimen exposed. The exposed end e is capable of receiving an impact from a hammer 11. The nature of the impact imparted to the specimen can vary without detracting from the reliability of the test, and no particular surface preparation is required for proper impact. A pair of sensors, 16, 17 are located along a chosen section of the specimen s, each sensor 16, 17 being capable of detecting an energy wave traveling along the specimen s. A timer 18 is operatively connected to the sensors 16, 17 in such fashion as to measure the time that elapses between detection of an energy wave at sensor 16 and its subsequent detection at sensor 17. This information is then supplied to a suitable memory circuit device 20 which can be set to compute the desired mechanical property of the specimen s, utilizing other known constants for the material, density measurements, and the known distance between the sensors 16, 17.

For mechanical grading purposes, a suitable grade marker or other device is used to visually imprint the specimen to show that the specimen meets or exceeds pre-selected minimum standards relating to the measured mechanical properties. Such mechanical marking devices are used in various installations today and well known in the industry.

If a second portion of the specimen s is also to be evaluated, a second pair of sensors 21, 22 are used along the chosen portion of the specimen s as shown schematically in Fig. 1. These portions may be overlapped as illustrated, or might be independent of one another. The sensors 21, 22 are shown connected to a second timer 23, which in turn is also electrically connected to the memory circuit device at 20, which can either average the two readings or treat them independently to produce evaluations of the mechanical properties of each portion of the specimen s. Where one is concerned only with the average mechanical properties for the entire specimen s, only two sensors need be used, each being located at the approximate ends of the specimen.

Figs. 2 and 3 show somewhat more specifically the physical arrangement of elements that has actually produced acceptable testing resuls. The specimen s is supported by a post 10 and a longitudinally spaced roller support 15. Additional supports can be utilized as necessary, depending upon the length and nature of a specimen. A clamp or hold down device 14 is illustrated as butting the side of the specimen s opposite to that which rests on the support 10, 15. It can be used during impact to prevent the specimen s from shifting lengthwise, but its use is not necessary in all applications of the present method. The particular nature of supports 10, 15 is not critical and they might take any suitable form that will carry the specimen.

The sensors 16, 17, 21 and 22 may be of any suitable type. The sensors detect the passage of the energy wave and direct a resulting electric impulse to the timing units. Such sensors basically fall into two groups, contacting sensors or non-contacting sensors. An exemple of a contacting sensor is a conventional accelerometer, activated mechanically by the shock wave through the specimen s. An example of a non-contacting sensor is one that is sensitive to the electric charge generated in the wood by the passage of the energy wave, this being known as the piezoelectric effect. A hooded conductive wire adjacent to the wood surface can be used as such a detector of this charge. This particular propery of wood is associated with the strain induced by the passing energy wave, therefore the passage of the energy wave and the generation of the piezoelectric charge along the specimen occur simultaneously at a given point adjacent to a sensor that is capable of detecting the electric

charge. This piezoelectric charge is identical to that produced in quartz crystal transducers.

The use of non-contacting sensors which are responsive to the piezoelectric effect of wood enables us to provide a method of testing wood specimens with increased speed and great simplicity of operation. No surface treatment is required since no surface contact is necessary. By eliminating the necessity of contacting the specimen surfaces, highly finished specimens can be accurately tested without risking damage to such surfaces and extremely rough lumber can be tested without further preparation.

The choice of a timing unit is not critical to the utilization of the present method. It must be capable of accurate measurement of time in the order of a few microseconds. Such accuracy is necessary in order to achieve meaningful measurement of the passage of an energy wave along short sections of wood specimens. The velocity ranges for such a wave in wood extend from about 10,000 feet per second to 25,000 feet per second. The measurement period along the 20 foot specimen therefore requires approximately 2 milliseconds.

Fig. 4 illustrates diagrammatically two natural defects in wood which are known to affect the modulus of elasticity and other mechanical properties. We have found that these natural defects modify the rate of propagation of an energy wave passing longitudinally along the specimen. The manner in which the change in rate is measured with respect to such defects is also illustrated in Fig. 4. For example, at the center of Fig. 4 a knot is depicted through which the energy wave must propagate. In this case, the knot, by virtue of its abrupt change in grain orientation with respect to the wood on either side, represents an impediment to the passage of the wave. The sensor 16 and the sensor 17 monitor the forward motion of the wave and cause the time interval between the sensors to be measured, and thereafter to be compared with other measurements along the length of the board.

Fig. 4 also illustrates cross grain on the right, a defect, contrasted to straight grain on the left. The energy wave propagates faster in a direction parallel to the grain than at an angle to the graph. Hence, the measurement of the rate of propagation at the two ends of the board in Figure 4 will reveal a difference in rate, and thus reveal a difference in basic properties.

From this description, it can be seen that the present method provides a rapid and effective means of numerically evaluating the variations in mechanical properties related to such strength reducing natural characteristics of wood over very short sections of the specimen. This can be accomplished by utilizing a succession of pairs of sensors along the specimen. This is advantageous, since the mechanical property along a portion of a structural wood member might render that member unfit for a particular purpose, although the recorded average value of the mechanical property along the total specimen might be within an acceptable numerical range. Table 1 sets out the time of passage for an energy wave along a series of sections located on boards tested, and illustrates the variation of the derived dynamic modulus of elasticity in each section. Taking Board No. 1, as an example, the modulus of elasticity (E_d) for the 14 sections varies between a high of 2.23×10^6 lbf/in^2 and a low value of 1.32×10^6 lbf/in^2. It also is to be noted that the low value of the derived modulus of elasticity within each occurs consistently with the highest time interval (Δt). Hence, this method provides a means for locating the weak portion either for the purpose of predicting other properties, such as tensile strength (later to be described), or for the purpose of upgrading by removing said portion.

TABLE I

Time intervals (Δt) and corresponding dynamic modulus of elasticity (E_d) values for 12-inch sections along the length of typical boards.

Board No. 1

Section No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14*
Δt (μ seconds)	57	56	59	54	59	61	57.5	60	55	58	60	62.5	64	70
$E \times 10^6$ lbf/in²	2.00	2.07	1.86	2.23	1.86	1.74	1.96	1.80	2.15	1.93	1.80	1.66	1.58	1.32

Density = 0.0174 lbs/in³; Average E_d = 1.83 × 10^6 lbf/in²

Board No. 2

Section No.	1	2	3*	4	5	6	7	8	9	10	11	12	13	14
Δt (μ seconds)	53	55	56	55	53.5	55	54	55	51.5	51	50	51.5	50	50
$E \times 10^6$ lbf/in²	2.28	2.12	2.05	2.12	2.24	2.12	2.20	2.12	2.42	2.47	2.57	2.42	2.57	2.57

Density = 0.0172 lbs/in³; Average E_d = 2.29 × 10^6 lbf/in²

Board No. 3

Section No.	1	2	3	4	5	6	7	8	9	10	11	12*	13	14
Δt (μ seconds)	50.5	50	52.5	49	52	51	51	50	49	51	50	54	51	52
$E \times 10^6$ lbf/in²	2.68	2.73	2.48	2.84	2.52	2.62	2.62	2.73	2.84	2.62	2.73	2.34	2.62	2.52

Density = 0.0183 lbs/in³; Average E_d = 2.64 × 10^6 lbf/in²

TABLE 1 (continued)

Board No. 4

Section No.	1	2	3	4	5	6	7	8	9	10	11	12	13*	14*
Δt (μ seconds)	51	54	61	59	56	62	58	63	58	57	61.5	61	65	65
$E \times 10^6$ lbf/in^2	2.55	2.28	1.78	1.91	2.12	1.73	1.97	1.67	1.97	2.04	1.76	1.78	1.57	1.57

Density = 0.0178 lbs/in^3; Average E_d = 1.88 $\times$ 10^6 lbf/in^2

Board No. 5

Section No.	1	2*	3	4	5	6	7	8	9	10	11	12	13	14
Δt (μ seconds)	55	56	53.5	55	52.5	52	52.5	53.5	50	52	51	53.5	49.5	51.5
$E \times 10^6$ lbf/in^2	1.97	1.90	2.09	1.97	2.17	2.21	2.17	2.09	2.39	2.21	2.29	2.09	2.44	2.25

Density = 0.0160 lbs/in^3; Average E_d = 2.5 $\times$ 10^6 lbf/in^2
*Area of low point E.

Numerical figures for dynamic modulus of elasticity set out in Table I are arrived at in conjunction with the present method by first weighing and measuring each specimen to determine its density. Since the density of wood varies from one specimen to another, it is necessary that this measurement be accomplished for each specimen for maximum accuracy. The specimen is then suitably supported and impacted to generate an energy wave traveling between the sensors located along the specimen. The elapsed time (Δt) required for travel of the wave between the sensors is recorded. This is then related to the distance of travel between the sensors to arrive at the velocity of wave propagation through this portion of the specimen. It is not necessary to record wave amplitude or other wave characteristics, thus no specimen end condition, nor special support design, are required.

The velocity of wave propagation is then used to calculate the dynamic modulus of elasticity by use of the formula: $E_d = C^2\rho$, where E_d is the dynamic modulus of electricity, C is the velocity of wave propagation and ρ is the density.

The above formula was derived from consideration of hypothetical prismatic rods of solid materials. We found that it can be applied to wood members with good approximation of the basic theory without need for complex formulas involving Poisson ratios, provided that the theoretical relationships between wave length and specimen width are not violated.

The capability and reliability of the present method have been demonstrated with respect to specimens of commercial lumber, logs and strips of veneer. Table 2 illustrates the corresponding measurement of the dynamic modulus of elasticity (E_d) arrived at according to the present method and the static modulus of elasticity (E_s) arrived at by conventional laboratory tests on the same specimens. Forty boards representing all structural grades of lumber from a producing region were used in the particular test. The range of E values extended from 2.65×10^6 lbf/in^2 to 0.90×10^6 lbf/in.^{2} respectively. The correlation coefficient between the two tests was 0.956 which indicates that the present method described herein is equivalent for all practical purposes to the more laborious laboratory method. Furthermore, it is readily adaptable to mechanical grading requirements in commercially acceptable speeds and quantities. The data of Table 2 is taken from the record of the 40 board experiment and lists the 5 highest and the 5 lowest values. These reveal the high correlation between this method and the laboratory method, and have the possibility of segregating the boards into suitable grade categories relating to use of structural lumber.

TABLE 2

Corresponding values of E_{static} and $E_{dynamic}$ of 40 pieces of 2 × 6 Structural Lumber

Specimen Number	$E_{static} \times 10^6$ lbf/in²	$E_{dynamic} \times 10^6$ lbf/in²
1	2.61	2.65
2	2.35	2.45
3	2.20	2.25
4	2.25	2.22
5	2.18	2.15
	etc	
36	1.25	1.33
37	1.23	1.32
38	1.19	1.10
39	1.02	1.02
40	0.95	0.85

Under the present design practices, 40 boards tested in the above group would be assigned a design modulus of elasticity not greater than the recognized average value for these species. By providing an efficient and practical method of accurately measuring modulus of elasticity on a production basis, the present grading procedure can reliably identify more narrow ranges of modulus of elasticity in a production run of boards, identifying grade groups both above and below the species average.

Another study was conducted on Hemlock structural lumber which had been visually graded as "construction". The objective was to determine reliable predictions of modulus of rupture values in tension and to thereby determine the grading potential of the present method. We found that the localized low point value of the dynamic modulus of elasticity was a more accurate predictor than the average modulus of elasticity of the entire specimen. A correlation coefficient of 0.80 was arrived at between the low point values of the dynamic modulus of elasticity and the destructively determined tensile strength. When the average modulus of elasticity is used in determining such tensile strength, a coefficient of only 0.69 is obtained for the same speciments. Examples of data for $E_{low\ point}$, Δt, $E_{average}$, and tensile strength are tabulated in Table 3 for both extremes of the values from an experiment involving 40 pieces of 2×6 construction lumber.

Table 3, like Table 2, presents data for the five highest and five lowest specimens in the 40 board experiment. The boards are listed in descending value of the low point dynamic modulus of elasticity. Also listed for each board is the time of passage of an energy wave over a twelve inch length and laboratory determination of average modulus of elasticity and tensile strength. Statistical analysis of the complete results of this series disclosed the improved correlation coefficient of the preceding paragraph, which results from the determination of low point modulus of elasticity according to the present method. Again this high correlation permits the segregation of lumber into grade categories to improve its utilization in applications in which tension stress is important.

It can also be seen from Table 3 that the time of passage of the energy wave may be utilized alone to predict the tensile strength without the intermediate step of determining the modulus of elasticity. This relationship would be useful in cases where greater speed of testing is desirable and high accuracy is not necessary. Other mechanical properties can be similarly predicted by this simplification in the method. By using constant sensor spacing and a species average density a predetermined relationship can be developed mathematically between the mechanical properties of a specimen and the measured time of passage of the

energy wave through the specimen. This predetermined relationship can then be used for production grading of specimens based upon the measured time alone.

TABLE 3

Corresponding Values of $E_{Low\ Point}$, Time Differential over a 12" Length (Δt), $E_{Average}$ and Tensile Strength of 40 Pieces of 2 × 6 Structural Lumber

Specimen Number	$E_{Low\ Point}$ $\times 10^6$ lbf/in²	Δt Microseconds	$E_{Average}$ $\times 10^6$ lbf/in²	Tensile Strength lbf/in²
1	2.93	48	2.63	8320
2	2.84	50.5	2.63	6350
3	2.60	53	2.65	6285
4	2.59	53	2.33	6590
5	2.57	54	2.60	5325
		etc.		
36	1.59	60	1.78	3815
37	1.51	59	1.87	2950
38	1.51	61.5	1.71	2825
39	1.39	63	1.72	3320
40	1.35	61	1.87	3750

With respect to the lumber tested in arriving at the data in Table 3, present practice assigns to all lumber of a species in such a grade designation only one allowable design value in tension. Higher values do exist in individual boards within this grade, and the present method permits accurate designation of higher value design values with respect to such boards.

The success attributable to the present method in determining modulus of elasticity for lumber led to a study of its application to veneer. No other practical method of non-destructive testing of veneer for grading by mechanical properties has been previously known. Even dead-loading to measure deflection — a technique frequently practiced on lumber — is not feasible with veneer because of the over-riding effect of warp which is commonly present in the latter. In this experiment, strips of veneer were supported and impacted as described above and subsequently tested by laborious laboratory procedures. The correlation between the dynamic modulus of elasticity arrived at according to the present method and the static modulus of elasticity arrived at by conventional tension methods was found to be 0.955. Examples of data at both extremes of an experiment involving 120 specimens of veneer are set out in Table 4. The dynamic modulus of elasticity values for the veneers range between 2.88×10^6 lbf/in² and 1.25×10^6 lbf/in². Again, the high correlation reveals that the method described yields information by which veneers may be graded for mechanical properties for improved structural products from veneer either in the form of plywood or laminated members.

TABLE 4

Corresponding Values of $E_{tension}$ and $E_{dynamic}$ of 120 Strips of Veneers		
Specimen Number	$E_{tension} \times 10^6$ lbf/in^2	$E_{dynamic} \times 10^6$ lbf/in^2
1	2.70	2.88
2	2.83	2.82
3	2.62	2.76
4	2.59	2.70
5	2.49	2.66
	etc.	
116	1.38	1.56
117	1.28	1.56
118	1.35	1.49
119	1.21	1.28
120	1.09	1.25

In addition to wood materials of regular cross section such as structural lumber and veneer, we have discovered that our method set out above is equally applicable to materials of irregular cross section. Naturally tapered dimensions of logs and poles present no difficulty in the utilization of this method, since the wave front which provides the signal for the measurement of the time interval is independent of the shape of the member through which it passes. Variations in cross section of test specimens cannot be handled by any other known type of non-destructive wood testing procedures for determining mechanical properties of the specimen.

We have tested green Douglas fir logs and rank each log according to the derived modulus of elasticity. The logs subsequently were cut into structural lumber and each board was then tested non-destructively by the above method and destructively to correlate its modulus of elasticity and its modulus of rupture. We have found that the ranking of logs by the present method successively predicted the relative quality of the lumber from the logs based on their average mechanical properties.

Table 5 records log-lumber test results which illustrate the ability of log grading by the present method to predict general lumber quality.

TABLE 5

General Lumber Grade Prediction through Log Tests			
Log Quality Rank (Based on E dynamic)	Log Number	Ave. Rupture, lbf/in_2	Ave. $E_{static} \times 10^6$ lbf/in^2
1	4	10,644	2.05
2	2	9,503	1.83
3	3	7,706	1.65
4	1	7,677	1.84
5	5	5,821	1.60
6	6	7,163	1.33

Log grading according to this method can be used in conjunction with logging and milling operations to best utilize each log being directed to a mill. As an example, logs of varying quality can be effectively allocated to such purposes as structural lumber, laminated products such as beams and plywood, and pulp and fiber products. This grading of logs prior to utilization can greatly improve the efficiency of a total wood processing arrangement and eliminate the current costly practice whereby logs are processed and irreversibly committed to a particular use before knowledge of true quality can be brought to bear.

Grade peerdiction in a log permits a mill to improve yield of higher strength structural lumber to meet particular customer demands. At the same time lower strength predicted logs can be cut for non-structural purposes, such as siding. Prediction of veneer strength from log ranking is also useful in statistically evaluating design strength of plywood for differing structural or non-structural purposes.

WHAT WE CLAIM IS:—

1. A non-destructive method of grading wood materials wherein mechanical properties of a wood specimen such as lumber, a log, a pole, a beam or a veneer are determined along a selected length of the specimen by means of a longitudinal energy wave propagation through the selected length comprising the following steps:

placing a sensor at each of the two ends of the selected length, each sensor being of a type capable of detecting the passage of an energy wave along the specimen;

physically impacting the specimen to set up an energy wave within the specimen traveling in a longitudinal direction along the selected length of the specimen between the sensors;

measurng the time of passage of the energy wave between the sensors;

and grading each specimen according to a predetermined relationship for its species between the mechanical properties of the specimen and the measured time of passage of the energy wave through the selected length.

2. A method as claimed in claim 1 further comprising the step of placing the sensors in pairs along a pluralty of successive portions of the specimen.

3. A method as claimed in claim 2, further comprising the step of determining the modulus of elasticity by relation of the measured time, measured separately for each portion, the density of the material of the specimen, and the length of each portion, and wherein areas of relatively low modulus of elasticity along the specimen are located and assigned values by means of such localized measurement of energy wave propagation.

4. A method as claimed in any one of the preceding claims, wherein the specimen is graded according to its dynamic modulus of elasticity as derived from the formula $E=C^2\rho$ where E is the dynamic modulus of elasticity, C is the velocity of wave propagation (selected length divided by time of passage of the wave), and ρ is the specimen density.

5. A method as claimed in claim 4, comprising the additional step of further grading the specimen according to a predetermined relationship for its species between ultimate strength and its dynamic modulus of elasticity.

6. A non-destructive method of grading wood materials such as lumber, logs, poles, beams, or veneers according to mechanical properties of wood specimens wherein said properties are determined along a selected length of a specimen by means of longitudinal energy wave propagation through the selected length thereof, comprising the following steps:

locating a first sensor in proximity to a surface of the specimen at one end of the selected length thereof, the sensor being of a non-contacting type responsive to the piezoelectric effect in wood;

locating a second sensor in proximity to a

surface of the specimen at the remaining end of the selected length thereof;

impacting one end of the specimen to set up an energy wave within the specimen traveling in a longitudinal direction along the selected length of the specimen between the sensors;

activating a timer responsive to signals from the first and second sensors and measuring the time of passage of the energy wave between the sensors; and

determining mechanical properties of the specimen as related to the measured time of passage of the energy wave through the selected length thereof.

7. A non-destructive method of grading wood materials wherein mechanical properties of a wood specimen such as lumber, a log, a pole, a beam or a veneer are determined along selected lengths of the specimen by means of energy wave propagation through the selected lengths thereof comprising the following steps:

placing a sensor along the specimen at individual positions located at each of the two opposite ends of each of the selected lengths thereof, each sensor being of a type capable of detecting the passage of an energy wave along the specimen;

physically impacting one longitudinal end of the specimen to set up an energy wave within the specimen traveling in a longitudinal direction along the selected lengths of the specimen between the sensors;

measuring the time of passage of the longitudinal energy wave between the sensors located at the ends of each selected length of the specimen; and

grading the specimen according to its dynamic modulus of elasticity as derived for each selected length thereof from the formula: $E=C^2\rho$ where E is the dynamic modulus of elasticity, C is the velocity of wave propagation (length of the selected length divided by the time of passage of wave) and ρ is the specimen density;

and further grading according to a predetermined relationship for its species between ultimate strength and said modulus of elasticity.

8. A non-destructive method of grading wood materials, substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

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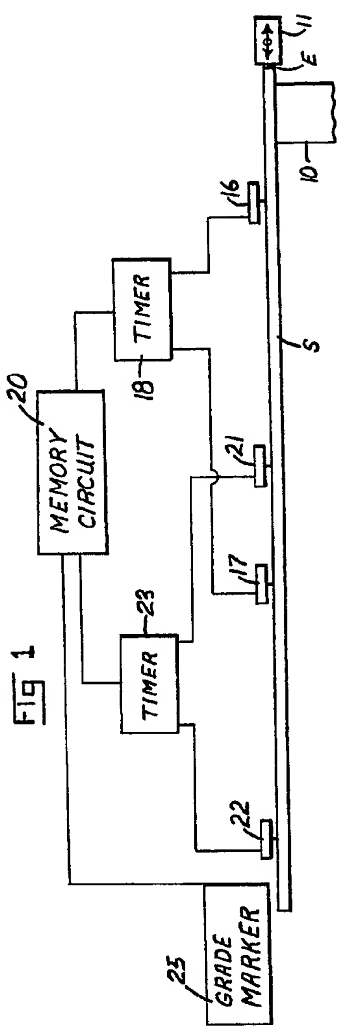

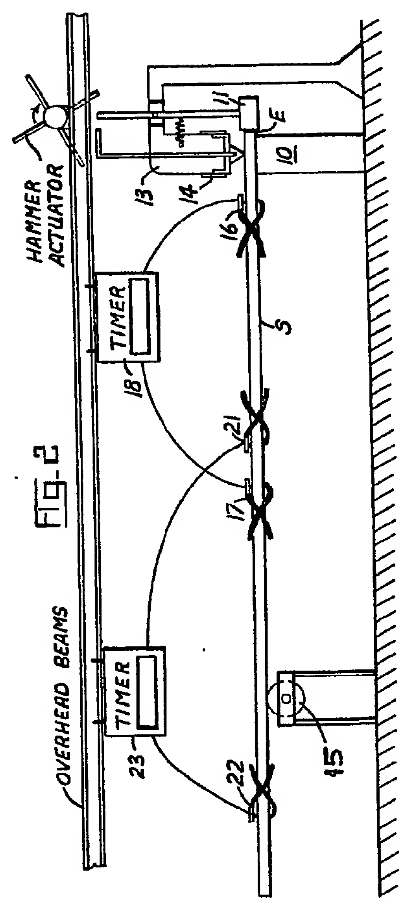

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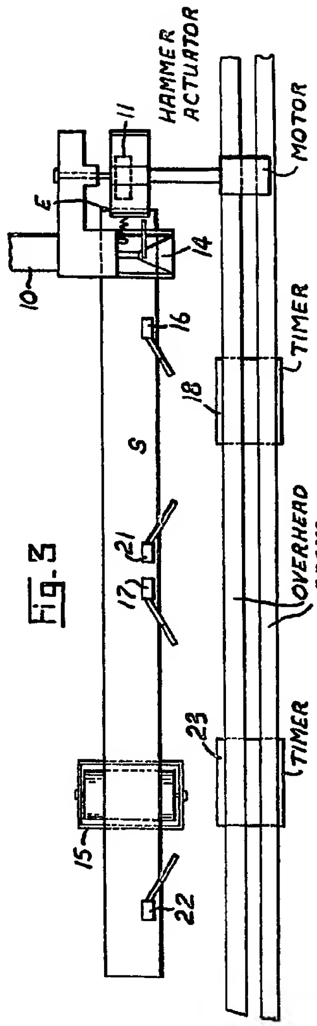

Fig. 3

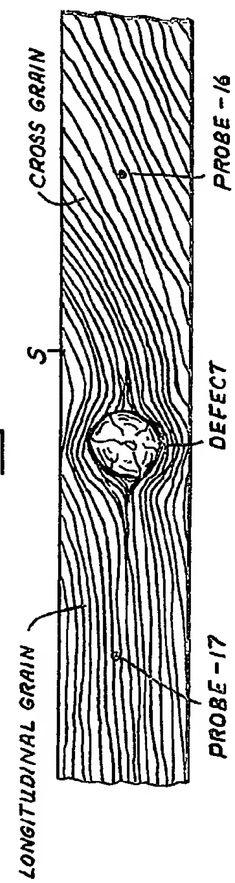

Fig. 4